

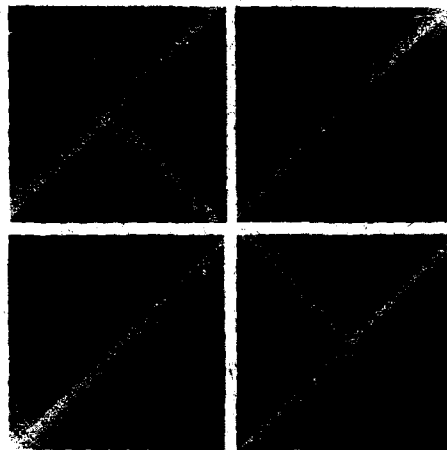
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Application of
Information System
Technology to K-12
Education



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Dr. Barry M. Horowitz
Dr. Peter J. Negroni
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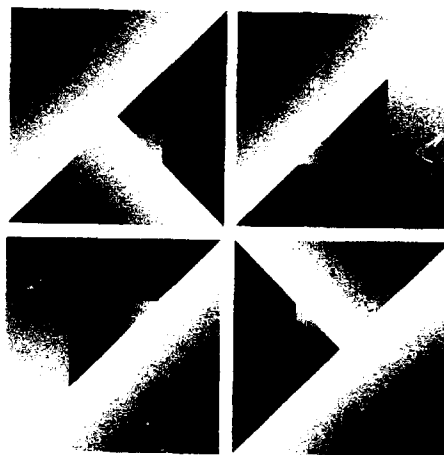
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PREFACE

Information system technology has revolutionized how modern business and government organizations operate. That same technology holds great promise for helping to improve K-12 education, but for a variety of reasons the public schools lag other sectors in taking advantage of the technology that is already available. If technology is to make a difference in public education, it must be integrated into the overall curriculum in the schools, and it must be implemented in ways that are both affordable and sustainable. This paper argues that key steps in this process are establishing a set of flexible standards for educational technology, promoting the sharing and reuse of educational technology materials, and creating a peer review process for the selection of educational technology products. The paper concludes by describing how these ideas are being pursued in partnership with the Springfield, Massachusetts, school system.

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TABLE OF CONTENTS

SECTION	PAGE
INTRODUCTION	1
TECHNOLOGY IN PUBLIC EDUCATION	2
Computer-Aided Instruction	2
Simulations	2
Curriculum Management and Assessment	3
EDUCATIONAL TECHNOLOGY OUTSIDE THE SCHOOLS	3
THE REAL WORLD OF THE PUBLIC SCHOOLS	5
Computers Are Not Enough	5
Computer Software — Too Much, or Not Enough?	6
Staff Training and Involvement	6
The Schools Are Not Rich	7
Nobody Is In Charge	8
THE IMPORTANCE OF STANDARDS	9
Open Systems	9
Sharing and Reuse	9
User Interfaces	10
Technical Support	11
GETTING STARTED	12
Start at the Local Level	12
Work With a School System That Wants To Improve	13
Create an Industry/Government Partnership	14
Follow an Evolutionary Approach	14
Help the Teachers	15
REFERENCES	17
APPENDIX — EXPERIENCES WITH ONE COMPUTERIZED ASSESSMENT SYSTEM	18

LIST OF FIGURES

FIGURE	PAGE
1. Educational Computer Market Share	5
2. Types of Educational Software	6

INTRODUCTION

We believe that modern information system technology — computers, software, communication networks, etc. — can make an important contribution to the revitalization and improvement of K-12 education. The application of technology to education is not a new idea, but the results to date have generally been less than originally hoped. The business community, government, and the military have been leaders in the development and application of information system technology, including its application to education and training outside the confines of the public schools. Fortunately, the schools can take advantage of the lessons that have been learned by these pioneers. One of the key lessons is that if the technology is applied in a piecemeal fashion to solve individual problems, the result will be a collection of individual and incompatible solutions that will eventually become unwieldy and unsupportable and will have to be replaced by a totally new system.

We need to help the public schools follow a path that will address two key issues at the same time: (1) how to make effective use of modern technology as an integral part of the overall educational process, and (2) how to implement that technology in the schools in a way that is affordable and sustainable. The first issue lies within the educational domain, and the second lies within the technical domain. Both are critical, and both need to be addressed concurrently. This paper explores three basic themes for dealing with the issue of how to implement technology in the public schools. These are things that can and should be done at the same time as educators are determining what technology is most useful in the schools and how it can be integrated into the total curriculum. Our three themes are:

- Flexible standards need to be established to guide the development and use of educational technology, particularly educational software. Standards are needed for the students' and teachers' interactions with the software packages, the hardware environments in which

the software operates, the collection and storage of data that can be used to help assess student learning, and the collection and sharing of descriptive data and user evaluations of educational technology products. Standards can make the technology easier to learn, and less costly to integrate and support. They can also make the educational market more attractive to product developers by providing access to potentially large markets for products that conform to the standards. Finally, standards provide the foundation for sharing and reusing educational technology materials to minimize the need for custom development and integration by local school districts. The standards must be sufficiently flexible to permit new innovations and to provide as much latitude as possible in how teachers can use the technology in their classrooms.

- A peer review process is necessary for educational technology products, analogous to the processes that already exist for textbooks, if technology is to become part of the educational mainstream. The peer review process will have to address software, courseware, multimedia resources, etc., in terms of standards and criteria that cover both educational quality and technical characteristics. The process must be designed to permit appropriate trade-offs related to flexibility within the standards.
- Neither the standards for educational technology nor the peer review process exist today, yet they are crucial if the potential benefits of the widespread use of that technology are to be realized. We plan to begin the process of creating these key elements by working with the Springfield, Massachusetts, public school system to become a leader in the development, evaluation, and refinement of the necessary sets of standards. We also believe that the Commonwealth of Massachusetts can create a peer review system for educational software that will lead to a nationwide role.

TECHNOLOGY IN PUBLIC EDUCATION

Technology is becoming increasingly important for the public schools, both as a tool to aid the learning process and as a subject to be studied in its own right. Information system technology — computers, high-speed worldwide communication links, videotapes and videodisks, CD-ROMs (compact disk — read-only memory), and more — have led to dramatic changes in the way business, industry, and the government operate. The application of this technology to the public schools has been much less dramatic. Education is inherently a labor-intensive enterprise. Labor constitutes nearly 93 percent of the cost of operating the educational system in this country; this is nearly twice the labor cost component of the average industry. It is unrealistic to assume that technology will replace teachers in the educational environment; rather, it will supplement and extend what the teachers are able to do. Over time, as the value of technology in improving education is demonstrated, the nature and composition of the classroom and the role of the teacher may change.

Computer-Aided Instruction

Throughout the past 30 years there has been interest in using computers to deliver instruction to students. The labels have shifted from the teaching machines of the early days to computer-based training (CBT), computer-aided instruction (CAI), computer-managed instruction (CMI), and the currently emerging integrated learning systems (ILS). The capabilities range from relatively simple page-turning and rote drill programs to highly interactive multimedia packages and an emerging class of intelligent tutors that combine a model of the student's learning process with an expert's subject matter knowledge base to provide instruction and coaching that is tailored to the individual student. In any of its forms, the key advantages of computer-delivered instruction are that it permits the individual student to progress at his/her own pace, the computer acts as an infinitely patient individual instructor, and the feedback from the computer to the student is instantaneous and non-judgmental. One thing that

seems clear is that it works; a study by the Hudson Institute cites 20 years of research that shows that computer-based instruction produces at least 30 percent more learning in 40 percent less time and at 30 percent less cost.

Simulations

Computers can be used to create learning environments that go beyond the computer-aided instruction model. The computer can be used to represent the behavior of the real world so that a student can learn by doing — by performing experiments and trying out ideas in a controlled but realistic environment. For example, the computer can be used as a physics laboratory in which the movement of mechanical objects is modeled in accordance with Newton's laws of motion. Experiments can be conducted with these simulated objects much as they could be conducted with real objects in a conventional laboratory. The difference is that the computer simulation permits the student and the teacher to expand the scope of their experiments to learn more about the laws of physics. The experimental setup — for example, the number, sizes, shapes, mass, and positions of the mechanical objects — can be quickly changed and rerun by changing parameters in the computer. The experiment can be run in real time, or it can be run in slow motion so that the student can see the details of what is happening. The experiment can be run in a variety of environments — at sea level on the Earth's surface, in a vacuum, on the moon, and on Jupiter — to show the effects of factors such as gravity and the atmosphere. The computer can provide results and feedback in a variety of formats — text, graphs, or pictures — to match the student's needs and mode of learning. The computer can also record quantitative data from the experiment so that the student can analyze it, plot it, and include the results as part of the lab report. Similar computer-based simulations can also be used for subjects that are governed by relationships more complex and less understood than the laws of physics — for example, the stock market, or a city. Interactive simulations provide an opportunity for students to develop and practice problem-solving skills that go beyond the absorb-some-material-and-pass-a-test model.

Curriculum Management and Assessment

There is growing concern that a high school diploma should signify that a student has achieved a certain degree of competency in critical areas of study, not simply that the student has passed a prescribed number of courses and standard tests. Any performance-based curriculum has to accommodate the fact that not all students learn at the same rate or even in the same way. Each student's educational progress needs to be monitored so that problems can be detected early and the instructional material, instructional approach, and instructional sequence can be adjusted on an individual basis to best serve the student's needs. Monitoring and assessing student progress is an inherent element in the educational process, and teachers do that as a normal part of their job. At the beginning of the school year, the teacher may know little about individual incoming students beyond the fact that they presumably received a passing grade in any prerequisite subjects. The formal student performance database today consists of the teacher's gradebook with grades for tests, quizzes, and possibly homework; the permanent transcript of course grades; and some standardized test scores.

The computer offers opportunities to help in this area by maintaining more detailed information on each student's performance, by scanning and analyzing that data to detect strengths and weaknesses, and by providing rapid feedback to the teacher (and to the student) so that the work in the classroom can be adjusted as necessary to optimize the learning opportunities for each student. A computerized curriculum management and assessment system could handle a range of data to help the teacher and the student. For example, besides keeping the student's grade for a test, it could also keep the student's answer to each question on that test. With that data, diagnostic analyses could be performed automatically to flag topics or techniques that a student, or a group of students, had difficulty mastering. The system could also identify additional or alternative material that could be presented to students to help them master the specific areas where they had problems. Such excursions and supplements would be within the boundaries of the

established curriculum but would provide alternative, tailored paths through the material. The extended student performance database would be maintained throughout a student's school career and would be available to successive teachers to provide them insights into the accomplishments, strengths, and weaknesses of the individual students at the beginning of a new class.

For such a system to be useful, it must capture the raw data on student performance directly rather than require the teacher or support staff to enter that data as yet another task; thus, it is a logical adjunct to computer-aided instruction. However, the system must do more than simply capture and store detailed data on student performance. It must do some preliminary analysis and interpretation of that data to help the teacher adjust the student's instructional path rather than simply burdening the teacher with a mass of data. The system must also provide its output quickly and directly to the classroom teacher so that the feedback can be used to plan the future work in the classroom.

EDUCATIONAL TECHNOLOGY OUTSIDE THE SCHOOLS

The business community and the military have been leaders in using computers and other technology to increase their productivity and to train their workforces. In a survey of Fortune 500 companies conducted four years ago, 54 percent of the respondents were using computer-assisted training, and 81 percent of the rest planned to do so within the next year or two. They were using it for the simple reason that it paid off in terms of money, time, and performance. Another survey of private companies conducted by the American Society for Training and Development in 1990 reported that computer-based training was considered to be the most cost-effective training technology by the 153 executives who responded. Eighty-one percent of the companies surveyed were using CBT, and 93 percent planned to be using it within three years. Examples of the range of applications of educational technology outside the schools include:

- Steelcase, Inc. uses an automated learning center with computer-based training and multimedia to train its employees to use personal computers in their jobs. The center operates on a drop-in basis so that employees can get the training they need when they have time available.
- Insurance companies such as Aetna and Massachusetts Mutual use interactive video technology and computers to create realistic simulations to train accident investigators and life insurance salespeople.
- Domino's Pizza is using interactive videodisk technology to train workers to mix pizza dough to ensure product quality and consistency.
- Federal Express uses interactive video instruction (IVI) to train data processing personnel. A comparison of IVI and conventional instruction showed that both approaches produced comparable performance but IVI took 60 percent less time.
- Martin Marietta uses computer-based training at individual employee workstations in a new, highly automated paperless factory. The computer serves as an on-the-job "instructor" who is always available, 24 hours per day.
- Shell Petroleum of Ireland, Pacific Bell, and Federal Express use interactive videodisk technology to teach defensive driving to their truck drivers.

Computer-assisted instruction is widely used throughout the armed services. The defense department has the problem of training hundreds of thousands of people each year, ranging from new recruits who need training in basic skills to officers and enlisted personnel who need to learn highly specialized tasks. Examples of the use of educational technology in the military services include:

- The Defense Language Institute in Monterey, California, uses personal computers and teleconferencing to help teach basic proficiency

in 20 foreign languages to 3,000 students each year.

- The Air Force uses computer-based training with digitized audio to teach 2,000 specialized cryptologic linguists each year in 12 languages. With this system, the student washout rate has been cut in half, from 10 percent of the class to 5 percent, while the student/instructor ratio has increased from 6:1 to 10:1.
- The Navy is using CD-ROMs and personal computers to provide 225 different courses to sailors at sea.
- The Navy uses personal computers with interactive videodisks to train medical corps staff in various health and health-related subjects such as hematology, dental technology, and emergency medical treatment.
- The Army is using interactive videodisk technology to train military officers in interpersonal leadership skills.
- The Army's Job Skills Education Program (JSEP) uses personal computers to provide basic academic instruction in reading and computation for Army recruits. The same program is being tested at several civilian sites to help teach basic skills in mathematics, reading, English as a second language, and other areas to immigrants and disadvantaged adults.
- The Air Force is developing an Advanced Training System that will consist of up to 35,000 networked computer workstations at six major air bases to provide training in more than 200 job specialty areas to as many as 175,000 students each year. This system will use the computers not only for the delivery of instructional material to the students but also for course development, student management, training resource management, and training evaluation.

The technology exists, and it works.

THE REAL WORLD OF THE PUBLIC SCHOOLS

It seems clear that technology can help to improve the public educational system in a number of ways. Possible roles range from acting as infinitely patient and non-judgmental individual tutors to changing the nature of work in the classroom, providing access to large repositories of information outside the conventional classroom, and maintaining detailed databases to permit teachers to assess the progress and respond to the learning needs of individual students. Many of these ideas are not new outside the educational system, and information system technology has had far more impact on business, industry, and the military during the past 20 years than it has had on education. Therefore, we need to look at what has been happening with technology in the public schools.

Computers Are Not Enough

The development of the low-cost personal computer in the late 1970s made it possible to begin to put computers into the classroom. PTAs sponsored bake sales to buy computers, and the business community was asked to contribute more computers or the money to buy them. Computer labs were created in the schools, and computer literacy became a high-priority addition to the school curriculum. U.S. schools acquired \$2 billion worth of personal computers during the decade of the 1980s. The growth has been rapid in recent years, and today there are more than three million computers in the public schools. By 1990, over 97 percent of all public schools had at least one computer. In Massachusetts, the number of computers in the public schools grew from 12,000 in 1984 to 48,000 in 1989. Nationwide, the ratio of students to computers has dropped from 125:1 in 1983 to 20:1 in 1991. However, during this same period standard school performance measures such as SAT scores have remained at best constant or have dropped slightly. Simply putting more computers in the schools doesn't necessarily improve educational performance.

Today one finds a variety of different and incompatible computers in the public schools (figure 1). The most popular machines change as time passes, reflecting the market dynamics and rapid pace of development in the personal computer field. Figure 1 shows that Apple is the largest single supplier of computers for schools. However, this aggregated data for Apple does not reveal the emerging shift from the earlier Apple II family of machines toward the newer and fundamentally different Apple Macintosh computers. IBM PCs and IBM-compatible clones are becoming more widely used in the schools, reflecting their dominance in business and the government. This diversity of hardware vendors is good for competitive reasons, since no school system (and no business or government agency) wants to become locked into a single supplier. On the other hand, the diversity of computer hardware brings with it potential problems in training students and teachers to use the different machines, in providing technical and maintenance support, in connecting the machines together so that they can communicate with each other, and in providing the software that is necessary to use the computers.

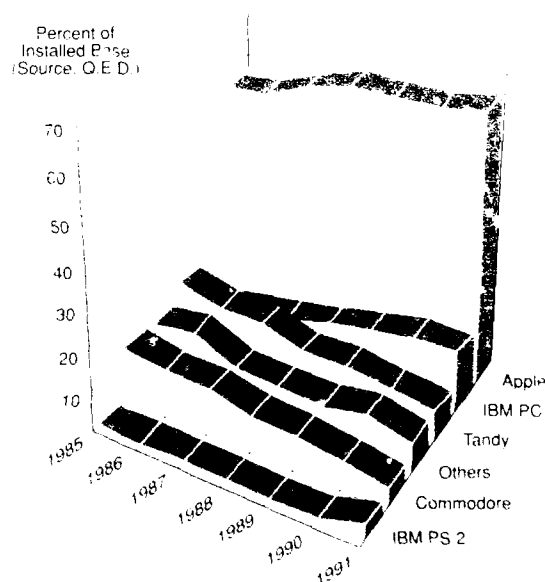


Figure 1. Educational Computer Market Share

Computer Software — Too Much, or Not Enough?

Everyone realizes that computer hardware is not very useful without software. At first glance, there seems to be plenty of educational software to choose from. One organization that prepares an annual survey of software for K-12 applications reports that some 13,000 educational computer programs have been offered since it began its surveys in 1985. Educational software is estimated to be a \$500 million per year business and growing, with as many as 900 companies in the field. As one might expect, the educational and technical quality of this software varies. Much of the educational software concentrates upon rote drill and skill practice; there is less software available that deals with concept development and demonstration, hypothesis testing, and simulations of the real world to provide a laboratory for learning (figure 2). Of the 13,000 educational computer programs that the organization cited earlier has reviewed during the past six years, only 900, or seven percent, have been recommended as being good products.

No single educational software company dominates the field; the top 10 firms accounted for an estimated \$200 million out of the total sales of

\$500 million in 1990. Many educational computer programs are developed by independent programmers, and consequently many educational software companies function more as publishers than as product developers. The market is also highly fragmented and scattered: each of the estimated 18,000 school districts in the country makes its own selection and purchase decisions. There are no federal or state standards for educational software, either in terms of educational content or technical design and implementation. With a large number of suppliers (most of them small), a wide range of computer hardware in the schools, a fragmented market, and no overall standards or guidelines, it is not surprising that educational software consists of a large number of pieces, some good and some not so good, that don't necessarily fit together in either the educational or technical sense.

Staff Training and Involvement

The current average of somewhat more than one computer per 20 students means that there is on the order of one computer per class. On the other hand, there are estimates that only between 20 and 50 percent of the nation's more than two million teachers use computers in their work. It is unlikely that a teacher will use technology effectively in the

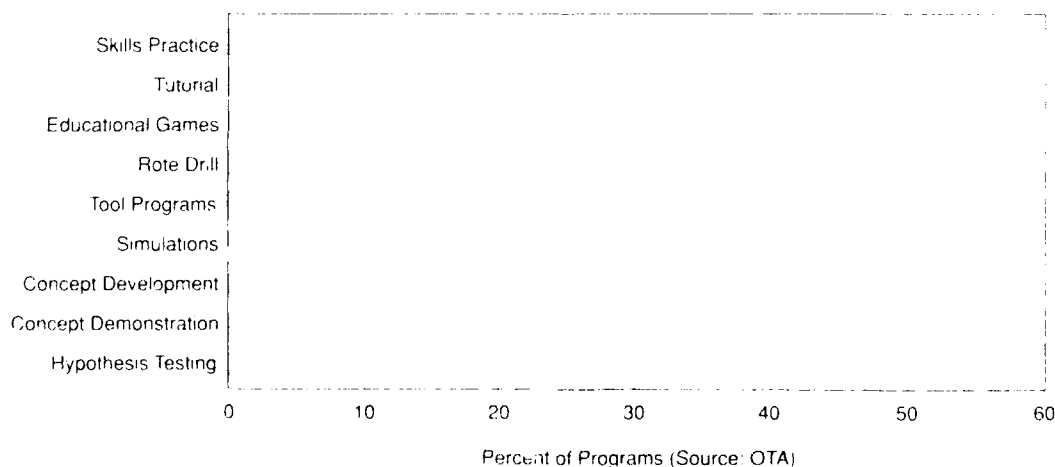


Figure 2. Types of Educational Software

classroom, even if it is available, if he/she has not been thoroughly trained in how to use it and does not feel comfortable using it in the presence of students. It is also unlikely that the technology will be available to the teacher in the classroom if the school administrators, school committees, and the community at large do not understand how it contributes as an integral part of the learning process.

Several years ago, it was estimated that only about one-third of all K-12 teachers had ever had as much as 10 hours of computer training. Even if the teachers have had some basic computer training, they face the problem of sorting through the hundreds or thousands of educational software programs that are available to find something that is high quality and relevant to their curriculum, and that matches their teaching style --- if they are involved in the selection process at all. Thus, it is not surprising that teacher training is one of the consistent problems cited in studies of why the promise of educational technology remains largely a promise:

"Few teachers have found ways to exploit the enormous potential which interactive technologies offer. . . . The computer can help shift the teacher's role from education dispenser to coach, guiding and encouraging each student to become an active participant in his or her own learning.

"The process by which teachers appropriate technology is more complex than that by which teachers adopt other changes. Initial fears regarding technology may need to be overcome before teachers feel in control. Training with computers is an ongoing process that takes place at varying levels, depending upon the teacher's responsibilities and the way technology is to be used. Teachers need opportunities for practice with the computer, with continuing support from trainers or computer using peers. Once teachers feel comfortable with the computer as a tool to help them do their job, they look for ways to integrate it into their existing curriculum and seek opportunities to do things previously impossible in the classroom.

"Teachers use computers in ways that work best with their own teaching styles and methods,

but those styles evolve as teachers gain more computer experience.

"The very opportunities opened by the computer can create more work for the teacher, making the job harder initially. Although the computer can minimize some administrative chores and ease classroom discipline, other tasks which accompany computer use (individualizing lessons, matching software to the curriculum, scheduling student computer time, monitoring use, providing assistance, and troubleshooting) add a net burden to the teacher's time in the short term.

"Any further investment in technology for education must factor in teacher training and support, whether that effort is focused on a few specialized teachers or on all teachers."

Power On! New Tools for Teaching and Learning.
Congress of the United States, Office of Technology Assessment, September 1988

Until the classroom teachers have sufficient training to feel comfortable using modern technology, it will not become an integral part of the learning process in the schools. Nobody claims that computers will reduce the need for teachers. The teachers will still be in charge of their classes, although their primary role may gradually shift from delivering information to overseeing and managing the learning process. Information system technology has demonstrated amazingly rapid growth and change during the past 30 years, and that pace is unlikely to slow down in the foreseeable future. There will be new things to learn and to try out, and training will be a continuing challenge. Formal training is expensive and time-consuming, and so the need is for educational software that is user friendly, with a standard look and feel to minimize the need for retraining each time a new software package or a new machine is introduced into the classroom.

The Schools Are Not Rich

The public schools clearly do not drive the development or application of information system technology. While U.S. schools may have acquired

three million personal computers at a cost of \$2 billion during the past 10 years, that is a small fraction of the 45 million personal computers that have been purchased by private businesses and the government during the same period. The \$500 million per year educational software market may seem substantial — until it is compared to the estimated \$30 billion per year that the defense department spends on software. A marketing research study in 1990 indicated that the typical public school would spend only \$35 per student — less than one percent of its budget — on information technology during the 1990-1991 academic year. In fact, the public schools are not even the dominant market for training materials. The total spending on public schools in 1990 was approximately \$200 billion; during the same period, business and industry spent \$210-250 billion for training. The business community has found that computer-based instruction pays off: worker-education departments of U.S. employers are now spending an average of 30 percent of their in-house education budgets on computer-based instruction — about 300 times more than the public schools spend on computer hardware and software for education.

While computer-aided instruction has been shown to be effective, it is also expensive in terms of initial development costs. Depending upon the nature of the subject matter, the degree of student interaction and branching that is provided, and the extent to which multimedia resources are used, the amount of development time required to create one hour of instruction to be delivered via computer ranges from 100 hours to 1,000 hours or more. This development effort requires skills in both the information technologies to be used, and the subject matter to be taught. At typical labor rates for high-technology industries, the cost of developing one hour of "courseware" (the instructional materials that are created for presentation to a student using a computer) can range from \$5,000 to \$50,000 or more. At these rates, the development cost for the courseware for a one-semester course might range

from \$50,000 to hundreds of thousands of dollars. Individual school systems have neither the money nor the market potential to rely upon custom-built educational software for their local needs. Clearly, the development costs need to be spread over as large a user base as possible. For example, if a package that cost \$100,000 to develop is used by 500 schools, its cost is only \$200 per school, and its value may span many courses and years of use. The schools will have to find, adapt, use, and share standard educational software and courseware, including that developed for the larger commercial and military markets.

Nobody Is In Charge

There is no overall focus, leader, or manager for the application of technology in the public schools. The majority of the funding, and therefore the control over what will be purchased and used in the schools, comes from the 50 state and 18,000 local governments that operate the schools. In 1989-1990, only six percent of the estimated \$200-215 billion annual budget for the public schools, or \$12-13 billion, came from the federal Department of Education, and as little as \$1-10 million of that total may have been devoted to the application of technology to education. In contrast, the Department of Defense spends on the order of \$200 million annually on research related to high-tech teaching and learning. There are of course many initiatives in the individual states and local schools to apply new technology. These range from simply putting more computers in the classroom to installing satellite communication terminals to support "distance learning" and building model "schools of the future" with multimedia technology and networked computers in every classroom. These localized initiatives are certainly helpful, but they run the risk of being fragmented and duplicative in whole or in part. In the absence of standards for the development and integration of educational software, it is unlikely that the products of local initiatives will be usable and supportable throughout entire states or the nation as a whole.

THE IMPORTANCE OF STANDARDS

The business community and the federal government have been leaders in the development and application of advanced information system technology over the past 30-40 years. During that period they have gone through at least four generations of technology and system architectures, starting with the original large mainframe vacuum-tube computers that operated in a batch-processing mode and progressing through transistorized computers, time-sharing systems, and minicomputers to the current generation of personal computers, personal workstations, file servers, and host processors all connected by communication networks. The public schools are much less advanced in this arena and have an opportunity to take advantage of some of the lessons that have been learned.

Open Systems

It is unrealistic to expect that computers built by a single manufacturer will eventually be the only ones to be used in the classroom. Competition among different companies is responsible for many of the advances in the performance of information systems and the reductions in the cost of the products. No consumer — public school system, business, or government agency — wants to become locked into a single source of supply. Furthermore, it is unrealistic to assume that computers built by a single manufacturer will be the best choice for all applications. Finally, the rapid advances in computers and associated equipment will continue, and consequently paths for upgrading current equipment must be available. Therefore, the preferred situation is to be able to mix and match hardware from different vendors and replace individual pieces of equipment with newer, more capable ones as they become available without having to scrap everything else. This situation can be achieved with an *open system architecture*. The open system philosophy is in contrast with earlier closed system architectures and proprietary designs that individual computer manufacturers developed to gain and maintain a competitive advantage.

The key step to building open systems is to standardize the interfaces, not necessarily the hardware itself. The interfaces that are important are the interfaces between individual pieces of equipment, the interfaces between the computer hardware and its software, the interfaces with communication links, and the interfaces with the users. This leads to standard programming languages, standard computer operating systems, standard representations and formats for data storage, standard database access languages, standard mechanisms for the protection of sensitive data, and standard communication protocols. Individual educational software packages will operate within this structure. Industry and the federal government have already come to the conclusion that open system architectures are the right approach for the future, and they have sufficient market dominance to force the hardware and software vendors to offer products that will work in an open environment. The public schools need to take advantage of this approach and the products that support it. There are no open system standards for the educational market yet, but they will be necessary and will most likely be closely related to the standards being implemented for the commercial and government markets.

Sharing and Reuse

Individual school systems cannot afford the custom development and integration of educational software for their own use. The same statement can obviously be made about textbooks, and no school system expects to develop its own textbooks. The alternative to custom development is the use of standard, compatible products that can be used by many schools. The need for standards is obvious: they permit development costs to be spread over a large number of users, and they ensure that the products meet at least a minimum set of requirements. Standards are beneficial to the producers as well; products that meet the standards have an inherent "seal of approval" and access to a potentially very large market. There already are standards and processes for the creation and selection of textbooks to support various courses and curricula. No standards and selection processes comparable to those for textbooks exist yet for educational soft-

ware, and an organization and mechanism to establish them is not in place. We need to find a way to create the necessary standards and processes if computer software and courseware are to become an integral part of the mainstream learning process in the public schools.

There are already a number of sources of educational software. They include commercial developers and publishers of products for the K-12 education market, other schools, industry (which has made major investments in technology for training), and various departments and agencies of the federal government (particularly the defense department which has been a leader in the development and application of computer-aided instruction). The open system architecture that has been described provides a framework that will permit hardware and software from different sources to be used in an integrated manner. While this open framework is necessary, it is not enough. A potential user — a classroom teacher or a student — needs access to the materials that already exist. This implies a need for databases and repositories that provide:

- Information on what is available, who uses it, and how to get more information — for example, what software is available for an IBM PC that provides instruction and problems in trigonometric identities, or what videodisks include still or motion images illustrating oil spills.
- An assessment of the quality and educational utility of products and resources that are available — sort of a Consumers Union for educational software, courseware, and other materials. The assessment has to be in terms of standard performance criteria and has to be based upon real experience by real users — students, teachers, and school administrators. The assessment needs to include performance measures (metrics) as well as subjective evaluations. In addition to covering the educational value, the assessment needs to cover the technical design and implementation of the product.
- The material itself — software, courseware, video, audio — in a form and format that is directly usable. Access for demonstration and evaluation should be possible.

These databases and repositories need to be comprehensive and easily accessible to the end users — the teachers who are planning and preparing lessons and courses, and the students who are doing projects or seeking supplementary information on a subject. The materials also have to be easy to use once they have been found, which leads to the issue of user interfaces.

User Interfaces

If computers are to be used effectively in the classroom, the users — the teachers and students — must be trained to use them and must find them easy to use. The need for open system architectures and the ability to use hardware from different vendors has already been stressed. Thus, the students may find that they are using different computers as they move from one subject to another, from one grade to another, or from one school building to another. Even if the same hardware is used in all subjects, grades, and buildings, the software packages will most likely be different. While this diversity takes advantage of the benefits of the competitive marketplace, it brings with it the need to train teachers and students how to use each software package on each machine. The costs and lost time associated with this retraining and the potential for errors as the teacher or student moves from one application to another can easily make the technology more of a burden than a useful tool. To minimize such problems, special attention has to be given to the interface between the computer and its users.

When typewriters first began to appear in offices, the importance of a standard keyboard was quickly recognized. All typewriter manufacturers adhere to a standard layout for the basic keys. The user's interface with a computer is more complex than a typewriter keyboard (although a standard keyboard is frequently an important part of the interface). The computer interface involves what the user sees on the computer display and how he/she

can interact with that display to control the operation of the machine. The two critical characteristics are that the user interface should be easy to use (user friendly) and consistent from one application to the next. User friendly interfaces permit the teacher and the student to interact with the machine by making choices from "menus" of options, by selecting things through pointing at pictures of objects (icons), and by other similar intuitive actions. Interfaces that require the user to master an abstract command language are less user friendly, require more time to learn, and require continued practice to maintain proficiency. Consistency means that the user interfaces for different applications should have a similar look and feel and produce similar results for similar actions so that a person who knows how to use one application does not have to start all over again to learn to use another. For example, some computers and software packages make extensive use of function keys ("F keys") to control processing. If with one application the F4 key causes the contents of the current display to be printed (saved) while with another application the F4 key causes the current information to be erased (destroyed), the opportunities for user confusion and error are obvious. The principles and standards of good user interface design have been learned from experience and can be applied to educational software to help reduce the training for new programs and to let the teachers and students concentrate on the subject matter rather than on how to cope with the computer.

The interface between the computer and the teachers and students can be thought of as the front end — the part that is immediately visible to the users. As technology becomes an integral part of the school environment, individual computers and software packages will not be used in isolation. Instead, the machines will be connected by communication networks so that students can work together cooperatively on projects and teachers can monitor student progress. A computerized curriculum management and assessment system was described earlier in this paper. For such a system to be useful, it must capture data on individual student performance. This becomes easier when computers are also used to deliver instructional material and to test the student's mastery of that material. In such an

environment, links between the computer-aided instruction system and the computerized curriculum management and assessment system are obvious and necessary. Again, standard interfaces, but not necessarily common hardware and software, are the key. These back end interfaces are not directly apparent to the students, but they are important if the teachers are to have direct, timely access to individual student performance so that the instructional process can be tailored to meet individual needs in time to make a difference.

Technical Support

The large-scale introduction of technology into the public schools means that an infrastructure of computers, software, communications networks, and related equipment must be installed, integrated, operated, and maintained to keep it working effectively. The need for this kind of technical support is well recognized in the business and government organizations that already have large automated information systems. Computer manufacturers and independent companies routinely provide the necessary technical support services — for a fee. The public schools are never likely to be able to afford professional engineering services at a rate of \$100,000 or more per staff year. Therefore, we need to find other ways to help the schools install, operate, and maintain their technology infrastructure.

The things that have already been described will help. Open system architectures will minimize the problems associated with installing, adding, and replacing hardware. Standards for educational software together with databases that identify what is available and how it performs will ease the selection and integration process. Consistent, user friendly interfaces between the software and the teachers and students will reduce the retraining load as new software is brought into use. These steps, in conjunction with technology training for teachers and other staff, may create a situation in which much of the necessary technical support can be provided by personnel in the schools. For example, one or a few teachers in a school might become the on-site computer experts and mentors for the other teachers and students in that school. They would be the ones

who answer questions when problems arise, and they would be the ones who first learn how to use a new software package and then show others in the school how to use it. This approach won't work if the on-site technical support role is simply added on top of those teachers' existing workload, so some accommodation such as additional compensation for extra time and/or a reduced teaching load will be necessary. Other possibilities exist within the context of the vocational high schools. Computer installation and repair is a major industry that will continue to grow, and the vocational schools need to train students to enter that field. Vocational students could provide technical support for school computers and communication networks as the hands-on part of their training, and that practical experience should increase their value to potential employers when they graduate.

GETTING STARTED

We began this paper by observing that technology is becoming increasingly important for the public schools, both as a tool to aid the learning process and as a subject to be studied in its own right. The application of information system technology in other areas during the past 20-30 years has hopefully taught us some lessons. The historical path has been expensive and slow. The process began by stimulating the demand and applying the new technology to specific problems on an *ad hoc* basis. Vendors developed and promoted proprietary products for their competitive advantage. Both products and applications grew, and the result after a while was an incompatible collection of "stovepipe" systems that become increasingly more difficult to integrate, expensive to maintain, and technologically obsolete as new products were developed that offered more capability but could not be integrated with what the users already had. Patchwork fixes were required to keep things running and to respond to new needs. Eventually, the need for standards, commonality, and an overall architecture and support infrastructure was recognized, and this led to the wholesale replacement of the earlier system and the investment in a new

generation of hardware and software. Unfortunately, the replacement of the earlier generation of systems is neither quick nor cheap. The conversion to open systems and standard products may take 5-10 years, during which time portions of the older system have to be kept in operation and supported while the new system is being put into place. The conversion or replacement of the software is more difficult and costly than the replacement of the hardware. The public schools do not have to start at the beginning and learn the same lessons on their own. Open system architectures and standard interfaces, sharing and reusing educational software from many sources, consistent and user friendly computer interfaces, and a technical support infrastructure that takes full advantage of resources in the schools themselves can be put into place at the same time that the schools are integrating technology into the educational process and curriculum. We need to demonstrate that this approach will make a difference.

Start at the Local Level

The federal government is not the major source of funding for K-12 education and does not currently have a role or mandate for establishing standards for educational technology. In fact, the federal government's current approach is to encourage local initiatives and private industry to create new "break the mold" schools, evaluate the results, and then decide which of the new ideas should be replicated in other schools. Therefore, we need to start at the local level as well. We have selected the Springfield, Massachusetts, public school system as a place to start. The Springfield system is large enough to present a broad range of challenges, but not too large. The system has 24,000 students in 40 schools. Thirty-eight percent of the students are white, 33 percent Hispanic, 28 percent black, and 2 percent Asian; 15 percent of the students are in special education classes. Currently, more than 40 percent of the students in Springfield drop out of school before graduating. More important, the Springfield school administration is interested in making systemic changes to improve the education for all students and is willing to take risks by trying new approaches. In 1991, the Springfield school

department began to explore the possible uses of technology throughout the school system and determined that technology could be central to the success of its program of school renewal in a number of important ways.

Work With a School System That Wants To Improve

Two and a half years ago, Springfield began a comprehensive school renewal effort with a plan that has a single goal: to offer all students access to equity and academic excellence, regardless of their ethnic, social, or economic backgrounds. In the first two phases of the program, Springfield restructured its schools by giving parents far more educational options than they had in the past while at the same time moving the system further toward the goal of racial balance. Next, they totally reorganized the grade structure of their schools by creating K-5 elementary schools, middle schools, K-8 schools, and four year high schools. Finally, they inaugurated school based management in all 40 schools. Having implemented these first steps in the restructuring process, Springfield has now begun a third phase in school renewal which is focused directly on making a positive impact on students and teachers in the classroom.

Central to this latest phase of renewal is the full implementation of a solid curriculum that specifies goals and outcomes for which both the schools and the students are accountable. Consequently, Springfield has begun to develop, with technical help from MITRE and assessment help from the Educational Testing Service (ETS), an assessment system that will monitor how well individual students and the system at large are achieving the goals that have been set in all curriculum areas. Springfield is developing its own assessment system because the assessment systems currently available to schools are inadequate for a number of reasons. First, they assess only a few of the curriculum areas that schools teach. Second, they assess only a small fraction of the goals and objectives that are covered by the curriculum areas that are tested. Finally, the data that schools do gain through currently available assessments is relatively inaccessible to classroom

teachers and is therefore largely unusable in making day-to-day educational decisions for students. The appendix describes one unsuccessful attempt to meet Springfield's needs with an existing assessment system.

Springfield has recognized that if schools are to do an effective job of teaching all students, they must do a much better job of managing instruction. If individual students are not achieving, teachers need to know exactly where they are having difficulty so they can intervene quickly with new forms of instruction to help them attain curriculum goals. If large numbers of students are not succeeding, teachers also need to know that quickly so they can develop new ways to deliver instruction for whole classes.

Technology is also being explored as a method of classroom instruction. It is clear that the classroom of the future will make regular use of a variety of technologies for direct instruction of all students. It is also clear that technology will help school systems meet the needs of students who have not succeeded in traditional educational programs (i.e., at-risk students). As was noted earlier, about 40 percent of Springfield students currently drop out of school. The system cannot accept this type of failure. Programs must be developed to keep students in school, but it is also important that these programs offer students a quality education and not just a diploma granted to them for seat time. Programs must be developed that incorporate the use of technology and are targeted for all students, whether they are at risk or not. The programs must challenge students and offer them genuine opportunities to learn the skills they will need to live and work in the 21st century.

Springfield's goal is to develop competency-based, alternative programs that take advantage of computers where appropriate to help manage the educational process and to help deliver instructional material. This will give students who, for one reason or another, are not succeeding in traditional programs the opportunity to learn required material at their own pace. Teachers will still play a central role in the education of these students. The teachers may

use a computer to help monitor student progress through the curriculum, but they must also establish ongoing, caring relationships with the students. A computer-based management system can help keep alternative programs such as this one — and the students in them — firmly connected to the curriculum and to the school system that is accountable for its quality.

A computerized curriculum management and assessment system is at the heart of Springfield's attempt to offer all students, regardless of their individual needs, the academic programs they require for success. It is basic to school renewal. For mainstream students, it offers constant feedback, allowing teachers to make adjustments in the content or delivery of lessons. For students with special needs, it keeps them within the curriculum in substantive programs, focused on outcomes they need to learn if they, too, are to receive a quality education that will mean something in the marketplace. In fact, such a system will become the foundation for all the programs developed in Springfield and for all further use of technology because it will interrelate and give teachers and administrators access to a number of important databases. The student database, which is currently isolated from instructional data, can be incorporated into the total informational grid. Information on student achievement could be merged with other student data and readily retrieved and shared with teachers, students, and parents. Teachers throughout the system would have timely information on instructional resources that could be used to teach specific curriculum goals and objectives. Computer-managed instruction would produce a flow of information for use throughout the entire system.

Create an Industry-Government Partnership

Many of the ideas in this paper have come from MITRE's work for its government sponsors, including work on the development of computer-based training systems for the military. MITRE's area of expertise is information system technology — computers, software, communication systems, etc. — for a wide range of defense and non-defense applications. MITRE is pursuing the application of

technology to the public schools as a *pro bono* activity consistent with its role as a not-for-profit corporation that engages in scientific and technical activities for the public good. However, the initiative will need the resources of other organizations if it is to succeed. The Air Force, specifically the Electronic Systems Center (ESC) of the Air Force Materiel Command, will be a partner with MITRE. The defense department and the Air Force are leaders in the application of technology to training and educational purposes, and there is a desire and an opportunity to transition technology that has been developed for defense applications to the civilian sector. ESC is the organization responsible for the development of advanced Air Force information systems.

Both ESC and MITRE are located in Massachusetts, which is the home of major computer manufacturers, software companies, and other high technology industry. As the initiative proceeds, we expect that a number of companies will also participate. While their initial participation may be to contribute goods or services, the reason why industry participation is critical goes beyond that. The theme of this paper has been the fundamental importance of standards for educational technology products. Industry is the developer and supplier of those products. By having industry involved from the beginning, the resulting standards and open system architectures will hopefully be viewed as steps that open new markets and therefore stimulate the development of more and better products.

Follow an Evolutionary Approach

The overall objective is to create a structure and approach for educational technology that can be used throughout a school system and eventually throughout the state and the nation. However, that objective will take time since it depends upon both the rate at which the necessary infrastructure can be developed and put into place, and the rate at which the schools can assimilate the changes. Therefore, we will begin with some specific activities that may be limited in scope but can serve to demonstrate and verify the basic concepts, and we will do that within the context of an overall vision of what we hope to

accomplish and a long-term plan for growth and expansion. Our near-term activities include:

- Creating several technology-based classrooms or an educational technology resource center in a Springfield school during the 1992-1993 school year. These will include a substantial number of computers for students and the teacher, interconnected with a local area network (LAN) and connected to external communication networks as well. They may also include multimedia devices such as CD-ROMs and interactive Videodisks. Different educational software packages and tools would be integrated in various ways and to various degrees to explore the impact of different user interfaces upon students and teachers.
- Creating a rapid prototype of a computerized curriculum management and assessment system that could be used to evaluate the utility of an expanded, accessible database on student performance as a monitoring and diagnostic tool for the classroom teacher. This prototype might deal with a single class, a few classes within a single school, or an entire school. Regardless of the initial scope, the underlying design must reflect and accommodate the educational curriculum and be scalable to permit expansion throughout the entire school system once the concepts and requirements are firmed up through evaluations with the prototype.
- Integrating the prototype computerized curriculum management and assessment system with the educational software packages in the technology-based classrooms to provide a vehicle for developing and evaluating both front end and back end interfaces in an integrated student-to-assessment system environment.
- Creating an easily accessible repository of educational technology materials (software, courseware, video, audio, etc.) within a school that would include not only the materials themselves but also descriptive information about them and evaluations by prior users to aid

students and teachers who are seeking material for classroom use or supplementary reference. The repository, which might reside in a computer in the technology-based classroom, would also be extensible by the users so that they could add to the evaluation database to reflect their own experience and suggestions.

- Preparing a master plan for the systemic use of educational technology in the school system in accordance with the concepts described earlier in this paper—open system architectures and standard interfaces, sharing and reusing educational software from many sources, consistent and user friendly computer interfaces, and a technical support infrastructure that takes full advantage of resources in the schools themselves.

Help the Teachers

Teacher commitment and early involvement are essential if any of these efforts are to succeed. We will bring the classroom teachers into the partnership in two ways: by providing training on modern information system technology, and by providing tools to help with portions of the teachers' workload. Modern office automation tools such as word processing, spreadsheets, computer graphics, and electronic mail can help the teachers in some of the administrative parts of their jobs. Other tools such as the computerized curriculum management and assessment system described earlier can help the classroom teacher concentrate on the overall management of the educational process for each individual student.

The industry/government partnership described earlier represents a substantial amount of technical expertise that can be tapped for initial training and technical support. The teachers who will use the technology will be involved in the planning and development process so that they will be comfortable using the products in the classroom. We have already taken the first step in that direction with a "Technology in Education" workshop at MITRE for 16 Springfield teachers this summer. We will foster

continued participation by working in the schools with the teachers during the planning phase to understand firsthand the challenges and the opportunities. We will also continue to bring selected teachers to industry for summer internships that will provide firsthand exposure to the kinds of technology that can be applied to the schools, further training in the use of that technology, and work on the detailed planning and implementation of subsequent phases of this program.

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APPENDIX

EXPERIENCES WITH ONE COMPUTERIZED ASSESSMENT SYSTEM

Prior to MITRE's involvement, Springfield made an initial attempt to implement a computerized curriculum management and assessment system for the Springfield schools, based on adapting an existing commercially available software package to that purpose. The existing package permitted users (teachers) to define and maintain a database of learning objectives for each grade and subject. Test questions keyed to the learning objectives could be entered and stored in a database and then used by teachers to create tests. Test results and other teacher assessments could be entered and various reports could be generated to assess student performance as well as the curriculum. The package also permitted the users to create a database of resources keyed to the learning objectives.

One of Springfield's first requests for MITRE support was to help determine if the package they had purchased would be adequate as a system-wide assessment system. After meeting with teachers involved in a pilot test of the package, it was found that the package was never used very widely within the school system for a variety of reasons:

- The user interface was complex and difficult to use. The original version of the commercial software package was released in 1979. The user/system interface was similar to other software developed in that time frame, with many levels of menus and function keys to select options. Users were required to make many selections to access a desired functional capability (e.g., to find a test question keyed to an instructional objective). In many cases, the user had to repeat the same process to make multiple selections (e.g., to create a complete test that covered multiple objectives). The depth of the menus also required effort to learn and

was easy to forget. Newer systems provide graphical user interfaces that are much more intuitive and easier to use.

- The existing software package did not allow a user to generate products (e.g., a set of test questions or report) that could be exported to a word processor for editing. Teachers had to print the test questions from the computer's database on paper and then literally cut and paste to create a test.
- The existing package did not provide the capability to generate and store graphics (e.g., charts, graphs) with test questions. Therefore, any graphics associated with a test question had to be stored in a separate physical file, or there had to be enough information in the test question to enable the teacher to construct the graphic manually.
- The software package had limited information security provisions. It provided access privileges to users by location, where a location corresponded to a school. If a user was given read/write access to a location, he/she could access and modify all of the teacher files for that location. Only the "owner" of an individual file should be able to modify the contents of that file, and only a subset of the users at any location should be permitted to examine an individual file.
- The database for this curriculum management and assessment system could not interact with the student database. The commercial package could import initial files of student and teacher data to set up its internal databases. However, after the initial setup, the databases had to be updated independently. Furthermore, the package could not export data to another database. Providing a database export capability would have required custom software development which the school system was unable to do.

The basic concepts underlying the commercial software package (i.e., defining learning objectives, and keying other information to the learning objectives) were consistent with the school system's objectives. However, limitations in the implementation made the package very difficult to use and required an inordinate amount of additional manual activity. Teachers were reluctant to learn the complex interface and became frustrated by the amount of effort required. The lack of information security also raised questions about student privacy rights and concerns over tampering with data. Finally, the inflexibility of the implementation made it very difficult to modify the package as the school system's needs changed. Unfortunately, these limitations were only obvious after an extended trial. In retrospect, this experience illustrates two of the challenges to be faced in applying technology in the public schools: (1) the difficulty of selecting a software package that will provide the capabilities that are needed for a specific application, that is easy to use, that can be integrated into a larger total operating environment, and that will provide a path for growth and adaptation; and (2) the importance of providing adequate training and continued technical support for the end users of software packages.